MONTHLY PROGRESS REPORT
MONTANA DOT “PERFORMANCE PREDICTION MODELS”
APRIL 2004

To:	**Susan Sillick, MDT; Jon Watson, MDT**
Contract No.:	**MDT HWY-30604-DT**
Contractor:	**Fugro Consultants LP**
Contract Period:	**June 2001-May 2006**
Prepared By:	**Jim Moulthrop, Project Manager**
Date Prepared:	**May 7, 2004**

PROJECT OVERVIEW

The overall objective of this research is to develop a design process and performance/distress prediction models that will enable the Montana Department of Transportation (MDT) to use mechanistic-empirical principles for flexible pavement design. The project involves a comprehensive performance monitoring and laboratory-testing program and spans a period of five years.

The specific tasks identified in the work plan are:

PHASE I
- Task 1. Literature Review
- Task 2. Review of MT DOT Pavement-Related Data
- Task 3. Establish the Experimental Factorials
- Task 4. Develop Work Plan for Monitoring and Testing

PHASE II
- Task 5. Presentation of Work Plan to MDT
- Task 6. Implement Work Plan – Data Collection
- Task 7. Data Analyses and Calibration of Performance Prediction Models
- Task 8. Final Report and Presentation of Results

CURRENT WORK ACTIVITIES AND COMPLETED TASKS

PHASE I

Task 1 – Literature Review

The purpose of the literature review was to summarize existing distress prediction models for load and non-load associated distresses and ride quality, for flexible pavements. The major types of distress considered were: *fatigue cracking*, *permanent deformation*, *thermal cracking*, and *ride quality*. The primary focus was on the models incorporated in the NCHRP 1-37A Design Guide, but other models were reviewed for their applicability to Montana materials, specifications, and conditions.

Completed: The “Literature Review,” summarizing the pavement performance models to be considered within this project, was submitted to MDT in October 2001.

Task 2 – Review of MT DOT Pavement-Related Data

Under this task, the typical pavement related data specific to the State of Montana was investigated and documented. This included typical pavement structures, materials, soils, climatic conditions, traffic, key modes of distress, maintenance strategies, and pavement data collection procedures normally used on Montana roadways. The two major sources of information were the MDT data and the LTPP data for experimental sites within and adjacent to Montana.

Completed: A review of the available pavement-related data specific to the State of Montana was completed and included in the Task 3 "Experimental Factorial" and Task 4 "Sampling and Testing Plan" submitted to the MDT in October 2001.

Planned: Because the LTPP database is updated periodically, to ensure the data is accurate and current, Fugro will perform a one-time final update of the calibration/validation database before the end of the project.

Task 3 – Establish the Experimental Factorials

The experimental factorials were established to ensure a statistically sound calibration process based on a database that covers the typical combinations of pavement structure, subgrade soil type, and climate conditions specific for Montana.

Completed: The "Minimum Data Elements" report and the "Experimental Factorial" were completed and submitted to MDT in October 2001. The factorial consists of 93 LTPP test sections of which 38 are in the State of Montana and the remaining 55 in neighboring States and Canada. In addition, 10 non-LTPP, supplemental sites were established and included in the factorial. These sites are: Condon, Deerlodge / Beckhill, Silver City, Roundup, Lavina, Wolf Point, Ft. Belknap, Perma, Geyser, and Hammond.

In March 2004, after a review of the results of the performance prediction analyses available to date, the team decided to include the two tentatively selected Superpave sites, Lothair and Baum Rd., in the group of non-LTPP sites. These sites were selected based on their geographical location and subgrade type in order to cover the whole range of climatic/subgrade conditions specific to Montana.

Task 4 – Develop Work Plan for Monitoring and Testing

Completed: A Work Plan was developed and provided to MDT in October 2001. The document contains the "Materials Sampling Plan," the "Initial Testing Plan" to document the baseline condition of each test site, the "Laboratory Testing Plan" to define the material properties and layer thickness at each test site, and the "Performance Monitoring Plan" to document time series data within the 60-month contract period.

The Performance Monitoring Plan was revised in a team meeting in March 2004 and is presented here:

- *Distress Surveys* Available: June 2002, June 2003; plan for June 2005
- *FWD* Available: August 2001, April 2002; plan for May 2004, March 2005

- *Profile* Available: October 2001; plan for May 2004, May 2005

<u>This Month:</u> Coordination efforts were made to schedule a comparison study in which Montana LTPP sections are tested in parallel with MTDOT's FWD equipment and LTPP's FWD equipment. The study is scheduled for May 6 – May 19 in Great Falls and Big Timber, Montana.

Task 5 – Presentation of Work Plan to MDT

<u>Completed</u>: The Work Plan (PowerPoint) was presented to MDT by the project team in October 2001.

<u>PHASE II</u>

Task 6 – Implement Work Plan – Data Collection

The monitoring and testing part of the project includes 93 LTPP test sections in Montana or surrounding States and 10 supplemental non-LTPP sites. While the monitoring and testing of the LTPP sites is managed through the LTPP program and all data of interest to the project can be retrieved from the LTPP database, the monitoring and testing of the non-LTPP sites has been managed and coordinated by MDT and Fugro. Therefore, the two categories will be presented separately.

LTTP SITES
There are 93 LTPP sites included in the experimental factorial. Of these, 38 are located in Montana and 55 in neighboring States and Canada. Assessing the availability of testing and monitoring data for the LTPP sites is a tedious and time-consuming process. In addition, with each update of the LTPP database the process has to be repeated. To minimize the time and effort allocated to this task the research team developed a calibration and validation database where all the data extracted from the LTPP database is stored. A set of queries was written that can be used at any time in the future to extract the data needed from the LTPP database to update the information in the calibration/validation database. The database is now complete and populated with LTPP data. A code that runs all queries automatically was used to populate the database and will be provided with the database. The population of the calibration/validation database with LTPP data is complete.

NON-LTPP SITES
The 10 non-LTPP sites are: Condon, Deerlodge / Beckhill, Silver City, Roundup, Lavina, Wolf Point, Ft. Belknap, Perma, Geyser, and Hammond.

<u>Completed:</u> The "Field Investigation Report" was completed and submitted to MDT in August 2002. The report included a summary of the distress surveys, field sampling results (cores, borings, and other geotechnical information), FWD deflections (Round 1 only), and longitudinal profiles from each of the supplemental sites. The Round 1 deflection tests were backcalculated and summarized. In addition, the Round 2 deflection testing was also backcalculated utilizing the same pavement structure information as the Round 1 data. Comparisons of the laboratory-derived values with FWD derived values were provided in the April and May 2003 monthly reports.

Unbound materials from the 10 sites selected in the experimental factorial were tested at the Fugro-South laboratory in Houston, Texas. Moisture-density curves at modified compactive effort (AASHTO T180) were derived for each of the 17 materials prior to testing. A repeated load resilient modulus test was performed for each material at optimum moisture content and maximum dry density (modified). The results of these tests were presented in the April and May 2003 monthly reports.

Asphalt concrete cores were retrieved from the 10 sites and tested. The tests performed were: indirect tensile (diametral) resilient modulus, indirect tensile strength, low-temperature indirect tensile strength, and low-temperature creep tests. All test results were presented in previous reports (March, April, May 2003 and February 2004). The results of low temperature indirect strength tests have been presented in Table 6.1 of the February 2004 monthly report. In addition, the strength and strain at failure will be calculated and included in the next monthly report.

Cores of cement treated/stabilized bases (CTB/CSB) were tested as well. However, due to specimen size requirements, only two of the seven treated base materials were tested for elastic modulus. Of the remaining five, four were tested for seismic modulus and one could not be tested. The results of the seismic tests were presented in the August 2003 monthly report. The modulus values obtained were highly variable with values of the coefficient of variation in most cases higher than 40 percent.

In March 2004, TTI performed diametral resilient modulus tests on the same samples to increase our confidence in the results of the seismic testing. Density tests were performed on five of the seven treated base materials and the results were included in the August 2003 monthly report. The results of the indirect diametral resilient modulus tests are summarized in Table 1.

Of the 5 CTB materials tested: Wolf Point, Lavina, Perma, Hammond and Roundup; for the Perma material, the results are still highly variable with a coefficient of variation of 63%. Although the variability “within sample” was very small (see column three of Table 1), the variability “between samples” is very high. This may be an indication of true variability within the material that may be due to construction practices, i.e. non-homogeneous distribution of the cement binder throughout the material.

For comparison, modulus values previously obtained from seismic testing (see August 2003 Progress Report) are given in Table 2. A comparison chart showing seismic modulus (Table 2) and resilient modulus (Table 1) values is given in Figure 1. As illustrated in Figure 1, the resilient modulus and seismic modulus follow a similar trend for Hammond, Roundup, Lavina and Perma. For Wolf Point however, there seems to be a high discrepancy between the values obtained with the two different methods. For purposes of this project, the resilient modulus values are preferred and will be used because the stresses and strains applied in the resilient modulus test are of the same order of magnitude with the stresses and strains caused by moving wheel loads in the field. For Perma, although the variation between samples is very high, the computed average of 661 ksi will be used as the best estimate available.

Table 1. Results of Indirect Diametral Resilient Modulus Tests on CTB Materials

Material	Specimen ID	Per Test M_R psi	Per Sample Average psi	Per Sample STDEV psi	Per Material Average psi	Per Material STDEV psi	Per Material CV -
Wolf Point	Wolf Point #3	1,132,468			**1,242,943**	**155,734**	**0.13**
		1,059,138	1,095,803	51,852			
	Wolf Point #3 Bottom	1,236,985					
		1,225,424	1,231,205	8,175			
	Wolf Point #2 Top	1,377,866					
		1,543,848	1,460,857	117,368			
	Wolf Point #2 Bottom	890,998					
		1,815,665					
		845,066	1,183,910	547,598			
Lavina	Lavina Top	940,667			**862,804**	**124,641**	**0.14**
		1,017,150	978,909	54,081			
	Lavina #2	564,069					
		809,785					
		719,809	697,888	124,316			
	Lavina #3	1,105,872					
		748,075					
		896,509	916,819	179,761			
	B Lavina #2	744,138					
		783,742	763,940	28,004			
	Lavina #1 Bottom	1,051,616					
		861,310	956,463	134,567			
Perma	Perma #1	737,653			**661,396**	**413,382**	**0.63**
		598,033	667,843	98,726			
	Perma #2	1,037,160					
		1,105,872	1,071,516	48,587			
	Perma #3	261,798					
		227,857	244,827	24,000			
Hammond	Hammond #2 Bottom	995,863			**754,570**	**150,147**	**0.20**
		867,685	931,774	90,636			
	Hammond #3 Top	545,596					
		786,402					
		735,183	689,060	126,856			
	Hammond #2 Top	738,798					
		885,370	812,084	103,642			
	Hammond #1 Top	419,013					
		630,218					
		706,848	585,360	149,069			
Roundup	Roundup #3	900,053			**867,862**	**77,633**	**0.09**
		961,811	930,932	43,670			
	Roundup #2	861,074					
		701,243	781,159	113,018			
	Roundup Top #1	949,156					
		833,833	891,495	81,545			

Table 2. Elastic Modulus Values from Seismic Testing

Sample ID	Average Height in	Average Diameter in	Weight grams	Bulk Specific Gravity	Young's Modulus ksi	Young's Modulus Average ksi	Young's Modulus C_v
Wolf Point 1	Tested in IDT	------	----	----------	----	---	------
Wolf Point 2	3.139	5.682	2835.9	2.257	798.6	665.9	0.28
Wolf Point 3	3.108	5.671	2862.3	2.265	533.2		
Hammond 1	3.080	5.665	2434.7	1.997	424.600		
Hammond 2	3.031	5.661	2546.5	2.077	1242.700	863.5	0.47
Hammond 3	3.096	5.658	2581.8	2.067	923.300		
Round Up 1	3.047	5.906	2810.8	2.197	1556.8		
Round Up 2	2.969	5.669	2516.1	2.157	470.5	1033	0.52
Round Up 3	3.102	5.894	2581.8	2.219	1071.7		
Lavina 1	2.928	5.909	2842.6	2.213	2809.800		
Lavina 2	3.073	5.912	3015.8	2.249	1364.100	1132.5	0.71
Lavina 3	3.126	5.906	3049.0	2.217	576.900		
Perma 1	3.475	5.663	2829.9	2.085	317.600		
Perma 2	3.070	5.661	2615.8	2.120	682.700	443.4	0.46
Perma 3	3.579	5.673	3020.7	2.095	329.900		

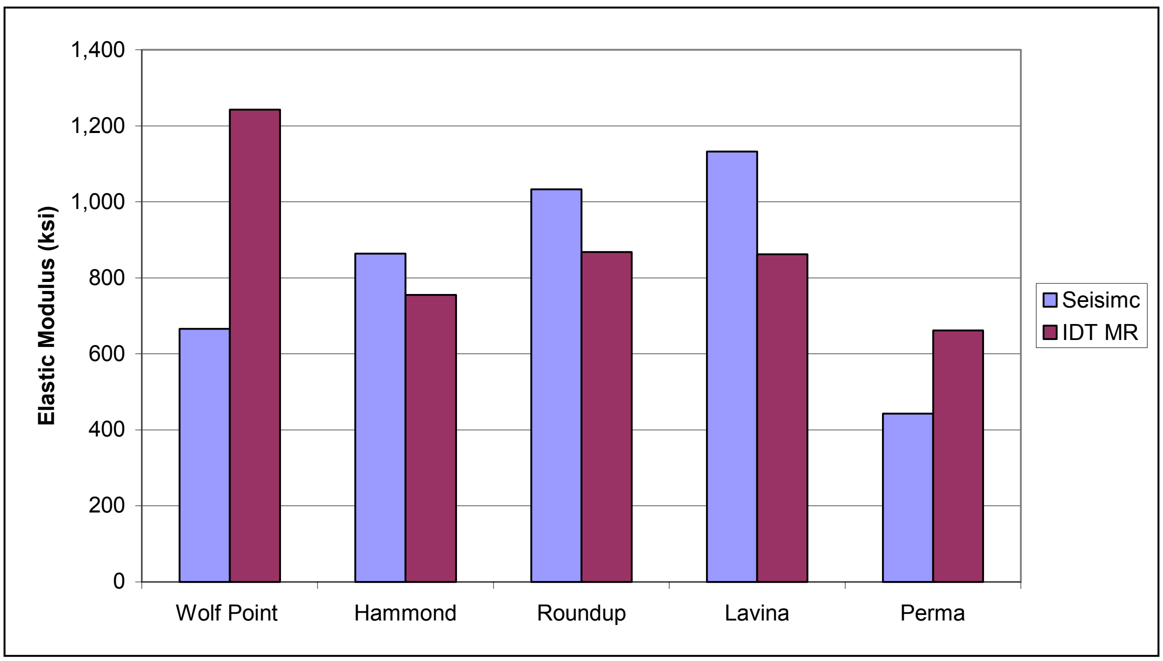

Figure 1. Comparison of Elastic Modulus Values from Seismic Testing and Indirect Diametral Resilient Modulus Testing

The rather limited comparison illustrated in Figure 1 shows that the results of seismic testing are different from the results of traditional IDT testing and seismic modulus values should be used with caution.

Two of the 10 non-LTPP sites, namely Deerlodge / Beckhill and Condon, contained "pulverized existing HMA and base materials," which were not sampled or tested. The layer moduli assigned to these layers in the calibration analyses are the ones backcalculated from FWD deflections.

SUPERPAVE SITES

In addition to the 10 non-LTPP sites, two Superpave sites have been selected to be included in the testing/monitoring plan. These sites are Lothair and Baum Rd. Samples of materials from the two sites have been received from MTDOT during 2003 and consist of binder cans, bags of bulk mix and buckets with unbound material. The materials have been stored off site in a temperature controlled storage room.

Laboratory testing of the Lothair and Baum Rd. materials started this month with the following material properties being measured:

HMA: Asphalt Content, G_{mm}, Gradation, Absolute and Kinematic Viscosity – all tests will be performed in our asphalt laboratory in Austin

Unbound: Gradation, Plasticity, Moisture-Density Curve (Modified Proctor) and Resilient Modulus – all tests will be performed at Fugro's geotechnical and materials testing laboratory in Houston.

Note that HMA cores are not available to test for indirect resilient modulus, tensile strength and creep. However, gradation, volumetric properties and viscosity can be used to predict the stiffness of the HMA layer using the "Witczak et al. Dynamic Modulus" predictive equation.

Task 7 – Data Analyses and Calibration of Performance Prediction Models

The first objective of Task 7 is to demonstrate the calibration technique required to develop and maintain the various model calibration coefficients that will be used by the department both now and in the future. As discussed with Montana DOT, four major distress types were considered in the experimental plan that require prediction models and calibration coefficients. These include fatigue cracking (both surface initiated and bottom initiated surface cracks), thermal cracking, rutting or permanent deformation, and ride quality. A second objective of this task will be the calibration and validation database, which will include all the data necessary to validate and calibrate the pavement performance models considered.

<u>Completed:</u> The calibration technique (or the specific steps required to determine calibration coefficients) was demonstrated to MDT utilizing models similar in nature to the NCHRP 1-37A Design Guide models. The project team made a presentation to the department in August 2003, which included a progress report, findings, and an illustration of the calibration exercise for the Silver City test section. A detailed discussion of the calibration algorithm accompanied by examples and step-by-step instructions will be included in a chapter of the Final Report.

The calibration and validation database has been finalized and populated with LTPP data. A set of queries was used to extract the data from the LTPP IMS database to the MDT calibration and validation database. These queries are supported by the current structure of LTPP Data Release 16 (R16). Changes to the structure of the data or the tables in future data releases will require modification/reconstruction, of the current set of queries. For example, the structure of the traffic tables in the data release Version 16 differs from those in the previous versions. The queries written to extract traffic data from earlier releases had to be modified to suit the table structures in the new release. However, such modifications to the LTPP tables are few in number. It is anticipated that further changes will be made to the traffic tables in the future LTPP data releases and hence the traffic queries may need to be updated in the future.

A macro was developed to run the queries in the required sequence to populate the calibration/validation database. The macro is designed to first clear existing data related to LTPP sites from the calibration/validation database and then to populate the database with the information from the latest LTPP data release. The macro was tested and the tables were filled with the information from the latest data release (R16). The calibration/validation database was sent to MDT (CD format) in January 2004.

An initial "Database Schema" was provided to MDT in October 2001 from the review of the LTPP database (Release11.5). The "Database Schema" was updated in June 2003 (Release 16).

An initial performance prediction exercise was performed for the 10 non-LTPP experimental sites. Material test data together with historical traffic and climatic data were used to predict the performance of these sites in terms of fatigue cracking and rutting in the asphalt concrete layer and rutting in the base and subgrade layers. Predicted distress was compared to results of the two distress surveys available for these sites (June 2002 and June 2003) and to the rutting measurements taken in October 2001. The results of this exercise were included in the July-September 2003 Quarterly Report.

A second performance prediction analysis, similar to the one performed on the non-LTPP, was started on the LTPP experimental sites. The availability of LTPP data was investigated in parallel with this study. While the performance predictions could be done by either spreadsheets or using the 2002 Design Guide software, the solution by spreadsheets was used primarily because the Design Guide software is not yet available. However, after a review and revision of the project budget this month, the study was suspended. The team considers that the performance predictions that will be performed using the 2002 Design Guide software are of greater importance and the funds available will be allocated to this effort.

An error in the units used for penetration values was identified in the LTPP database and the calibration/validation database: the LTPP data dictionary, data collection form, and data entry form all call for PENETRATION_77_F and PENETRATION_115_F to be reported in millimeters. The QC ranges (5-120 and 10-250 respectively) imply results should be in 0.1 mm. It is obvious that 250 mm (9.84 in.) far exceed the maximum measurement of the testing apparatus. It seems likely that values actually entered in the table are a mix of mm and 0.1 mm. A problem report has been submitted identifying the issue. At the earliest, this issue may be resolved with the next LTPP data upload, which will take place in May 2004 and the corrected data will be available only sometime in late June 2004 at the earliest.

Planned: Continue population of the calibration/validation database with information from the 10 non-LTPP sites.

Note that the calibration analyses performed so far do not specifically address the values of the calibration coefficients, but are limited to comparisons of predicted to measured distress using several widely used performance models (not necessarily the NCHRP 1-37A Design Guide models). Upon release of the NCHRP 1-37A Design Guide, the team will replace the current versions of the models with the Design Guide models and then proceed to the actual calibration of model coefficients. In addition, climatic/moisture data will be extracted from the Design Guide environmental database, which includes information for Montana and surrounding regions.

Task 8 – Final Report and Presentation of Results

No activity.

PROBLEMS / RECOMMENDED SOLUTIONS

No problems were encountered during last month and none are anticipated next month.

NEXT MONTH'S WORK PLAN

The activities planned for next month are listed below:

- Coordinate with MDT personnel on an as-needed basis.
- Continue populating the database with the data from non-LTPP sites.
- Perform FWD testing in Great Falls and Big Timber, Montana.
- Continue testing of Lothair and Baum Rd materials

FINANCIAL STATUS

The Financial Summary I table shows the estimated expenses incurred during the reporting period.

The Financial Summary II table provides the total project expenditures by the Montana and FHWA fiscal years in comparison to the allocated funds for each fiscal year.

The Financial Summary III-A chart illustrates total expenditures from inception of the project June 2000 through December 2003. The Financial Summary III-B chart reflects total project expenditures from January 2004 to the end of the project, May 2006.

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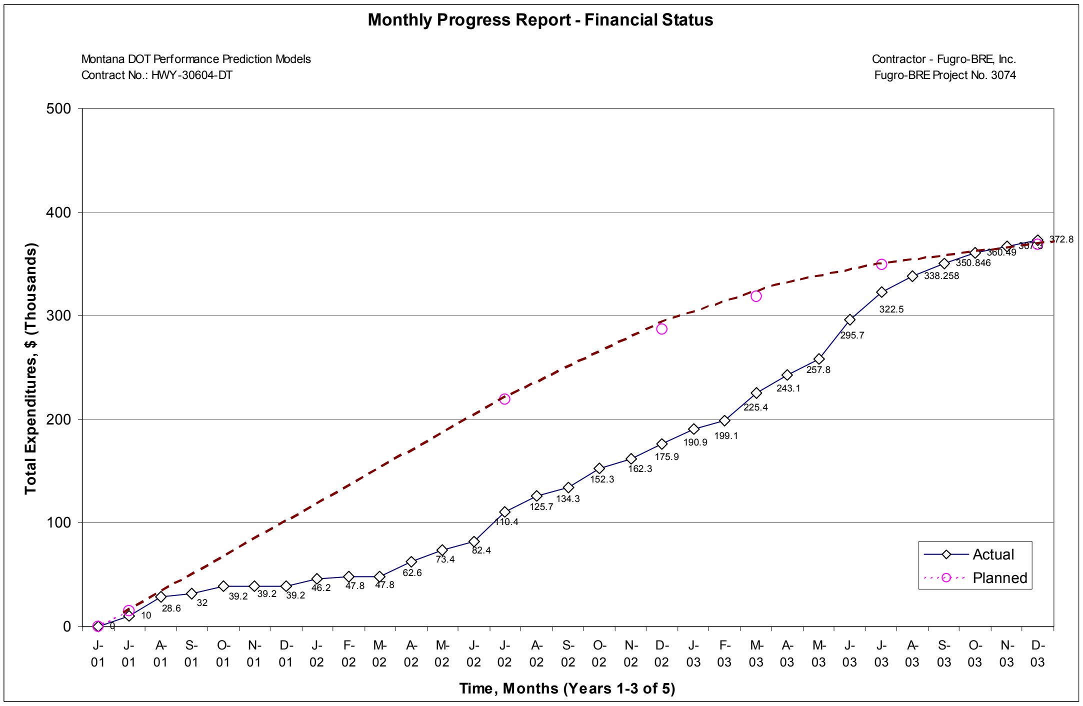
Financial Summary I
Estimated Expenses for Reporting Period: Fugro-BRE

Cost Element	Last Month's Cumulative Project Costs, $	Current Month's Expenditures, $	Cumulative Project Costs, $
Direct Labor	92,904	2,011	94,915
Overhead	132,853	2,876	135,729
Consultants/Subcontractors	4,050	0	4,050
ERES/ARA	26,953	2,346	26,953
Parsons-Brinckerhoff	12,093	0	12,093
SME	523	0	523
Dr. Matthew Witczak	0	0	0
Dr. Mark Hallenbeck	3,129	0	3,129
Travel	14,607	0	14,607
Testing	71,994	0	71,994
Other Direct Costs	6,489	125	6,614
Fee	36,560	501	37,061
TOTAL	402,156	5,514	407,670

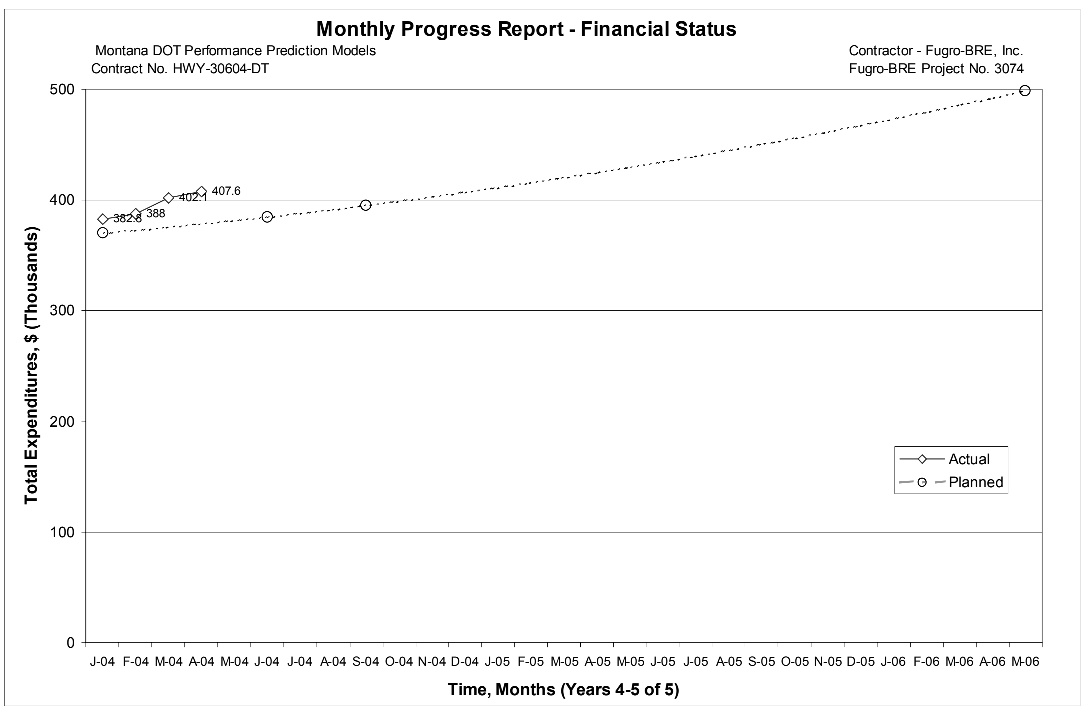
Financial Summary II
Total Expenditures by Fiscal Year: Montana and FHWA

MONTANA DOT FISCAL YEAR			**FHWA FISCAL YEAR**		
Fiscal Year	Cumulative Allocated Funds, $	Cumulative Expenditures, $	Fiscal Year	Cumulative Allocated Funds, $	Cumulative Expenditures, $
6/1/2000-6/30/**2001**	15,000	*0	6/1/2000-9/30/**2001**	65,000	31,996
7/1/2001-6/30/**2002**	218,969	82,420	10/1/2001-9/30/**2002**	258,969	102,303
7/1/2002-6/30/**2003**	348,969	213,291	10/1/2002-9/30/**2003**	358,969	216,187
7/1/2003-6/30/**2004**	388,969	111,959	10/1/2003-9/30/**2004**	398,969	57,184
7/1/2004-6/30/**2005**	428,969	---	10/1/2004-9/30/**2005**	438,969	---
7/1/2005-6/30/**2006**	498,969	---	10/1/2005-9/30/**2006**	498,969	---
TOTAL	498,969	407,670	TOTAL	498,969	407,670

*June 2001 expenditures were combined with July 2001 expenditures.



Financial Summary III-A: Total Expenditures by Month Jun 2000 – Dec 2003



Financial Summary III-B: Total Expenditures by Month Jan 2004 – May 2006